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Short communication

Trend analysis of rainfall and temperature in metropolitan cities of India using Mann-Kendall test

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A metropolitan city is a region which includes a major city and its suburbs, which is commonly characterized by its economic, social and cultural influence. Due to rapid urbanization, metropolitan cities attract many people to move to these cities for various reason such as job, education, healthcare, business etc. In 2018, the global rate of urbanization reached 55% and it is projected to 68% of the world's population will live in urban areas that by 2050, (Gupta, 2025). Climatic condition of metropolitan cities tends to change over time due to global climate change and localized anthropogenic activities such as urbanization, industrialization, pollution, rapid population growth etc (Kumar, 2021). Such activities alter land surface characteristics, increase heat absorption, and reduce evapotranspiration, contributing to the urban heat island (UHI) effect, which raises local temperatures, especially during nights (Nichol, 2005). The prolonged high temperature will lead to heatwave and heavy rainfall in a short span of time leads to urban floods and short rainfall leads to water crisis and increased dry period, these events are often occurring in these metropolitan cities and affecting the day today life of people (Matthews *et al.,* 2017). Analysing the long-term climatic pattern is very much important for monitoring climate and policy making (Santhoshkumar *et al.,* 2024).

The study aims to quantify climatic shifts, changing trend in seasonal climate pattern which provides actionable insights to support sustainable urban planning, disaster risk reduction and climate adaptation strategies in metropolitan cities of India. Scientific trend analysis, which employs robust statistical methods such as the Mann-Kendall test and Sen's slope estimator were used in this study.

Study area

In this study the six major metropolitan cities of India viz., Chennai, Hyderabad, Bengaluru, Mumbai, Delhi and Kolkata (Table 1) covering diverse climatological zones, represents the key urban centres in India that are highly sensitive to global warming and climate change are taken into account. Trend analysis needs extended time-series data to show changes in climate patterns and accurately identify rainfall and temperature trends. For this study, high-resolution gridded rainfall (0.25° X 0.25°) and temperature (1° X 1°) data is collected from India Meteorological Department for the period of 1951 - 2024 (Nandi *et al.,* 2023) and converted into monthly and for seasonal classification each year is divided into four seasons based on India Meteorological Department Winter (January–February), Pre-monsoon (March–May), Monsoon (June–September), and Post-monsoon (October–December) (Subash and Sikka, 2013).

Mann Kendall and Sen's slope

The Mann–Kendall (MK) test is a widely used non-parametric method to detect trends in time series data (Mann, 1945). Unlike parametric tests, the MK test does not assume any particular distribution of the data. Instead, it relies on rank correlation, evaluating whether values tend to increase or decrease consistently over time. The test statistic is calculated by comparing all possible data pairs in the series. A positive value indicates an upward trend, while a negative value indicates a downward trend. Similarly, a positive Z value suggests an increasing trend and a negative Z value suggests a decreasing trend. The statistical significance of the trend is determined using the standard normal distribution. The Sen's slope estimator is often applied in conjunction with the MK test to quantify the magnitude of the trend (Yadav *et al.,* 2014; Waghaye

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Table 1: Metropolitan cities with temperature and rainfall grid points

City	Temperature grid point		Rainfall grid point	
	Latitude (°N)	Longitude (°E)	Latitude (°N)	Longitude (°E)
Chennai	13.5	79.5	13.0	80.0
Hyderabad	17.5	78.5	17.25	78.5
Bengaluru	12.5	77.5	13.0	77.5
Mumbai	19.5	73.5	19.0	73.25
Delhi	28.5	77.5	28.5	77.0
Kolkata	22.5	88.5	22.5	88.5

Table 2: Variation of rainfall and temperature in metropolitan cities during different seasons

Season	Chennai	Bengaluru	Delhi	Hyderabad	Mumbai	Kolkata
			Rainfall (mm)			
Pre-monsoon	71.3	161.3	36.1	65.1	20.0	212.1
Monsoon	462.9	470.2	533.0	568.3	2194.0	1227.5
Post-monsoon	787.5	237.0	26.8	121.7	92.7	177.3
Winter	37.3	8.3	29.5	10.9	0.9	34.0
Annual	1358.9	876.8	625.4	765.9	2307.6	1651.0
			Temperature (^{0}C)			
Pre-monsoon	31.0	28.0	27.8	31.4	28.6	29.0
Monsoon	30.5	25.6	30.7	27.7	27.0	29.3
Post-monsoon	26.4	23.5	20.6	24.3	25.5	24.2
Winter	25.6	23.5	15.4	24.2	23.0	21.1
Annual	28.8	25.3	24.9	27.2	26.4	26.6

et al., 2018). Unlike ordinary least squares regression, Sen's slope assumes a monotonic (linear) trend but is more robust, as it is less sensitive to outliers and violations of normality assumptions

Seasonal and annual variation of rainfall and temperature

The analysis of seasonal and annual rainfall and temperature across six metropolitan cities reveals distinct spatial and temporal pattern in distribution (Table 2). In case of rainfall, monsoon is dominant and most reliable season in all cities except Chennai, where post-monsoon rainfall is highest due to Northeast monsoon season. Mumbai records the highest and most consistent annual rainfall while Delhi has comparatively low and highly variable rainfall. Winter and pre-monsoon seasons show minimal and highly erratic rainfall with high variability. Chennai and Mumbai exhibit clear seasonal dominance in post-monsoon and monsoon respectively. Whereas, Hyderabad, Bengaluru and Kolkata receive balanced rainfall during the monsoon with moderate variability.

The annual temperatures show high consistency across all cities (Table 2). Chennai exhibits the highest and most stable annual mean temperature followed by Hyderabad and Kolkata. Delhi shows the greatest seasonal temperature contrast with low winter temperature. Monsoon temperatures are consistently moderate across all cities, indicates strong climatic control during the season. Pre-monsoon is the warmest season for most cities, while winter is the coolest. Bengaluru maintains the mildest and most uniform temperature profile throughout the year.

Trends in rainfall and temperature across the cities

The rainfall and temperature trend across the six metropolitan cities shows mixed spatial pattern (Table 3 and 4) in seasonal and annual scale. The rainfall and temperature trend analysis for six major Indian metropolitan cities reveals distinct spatial and seasonal patterns. At annual scale, rainfall shows a significant declining trend in Delhi (–5.40 mm/year, $p < 0.001$), it indicates reduction in water availability. Mumbai (–8.10 mm/year) also shows non-significant declining trend. In contrast, Hyderabad records significant increase (+2.87 mm/year, $p < 0.05$) and Chennai shows a weak but positive rise (+3.45 mm/year, $p < 0.1$). Bengaluru (1.0082) and Kolkata (-1.2625) show slight non-significant decreases in annual rainfall. The seasonal rainfall study revealed that the significant monsoon decline in Delhi (-4.3964) and Kolkata (-3.0431) were observed, which is both crucial for regional water resources and agriculture. However, Hyderabad shows increasing rainfall during pre-monsoon, monsoon and winter seasons, suggesting that redistribution of precipitation that may benefit agriculture and water recharge. Chennai (1.6250) records a marginal increase in monsoon but there is no positive significance in post-monsoon rains, whereas other cities mostly show non-significant decline.

Temperature trends are shows more consistent among most of the cities. Almost all cities, except Delhi, show significant warming annually and seasonally. Chennai and Bengaluru recording the steepest increases across all seasons, particularly in winter and post-monsoon seasons. Kolkata and Hyderabad also exhibit strong warming, while Mumbai records consistent rise except in the pre-monsoon and winter slopes. Delhi diverges from the national urban pattern showing weak negative or flat temperature trends across seasons, likely due to aerosol dimming, high pollution levels or localized urban heat island effects masking warming.

Table 3: MK trend test for rainfall and temperature across various cities for different seasons

Seasons	Chennai	Bengaluru	Delhi	Hyderabad	Mumbai	Kolkata
			Rainfall			
Annual	↑	↑	↓***	↑*	↑*	↓
Pre-monsoon	↑	↑	↑	↑*	↓	↑
Monsoon	↑	↑	↓***	↑*	↑*	↓*
Post-monsoon	↑	↑	↓*	↓	↑	↓
Winter	↓	↓	↓	↑*	↓	↓
			Temperature			
Annual	↑***	↑***	↑	↑***	↑***	↑**
Pre-monsoon	↑***	↑***	↑	↑	↑***	↓
Monsoon	↑***	↑***	↑	↑**	↑***	↑***
Post-monsoon	↑***	↑***	↑	↑***	↑***	↑**
Winter	↑***	↑***	↓	↑	↑*	↓

Where, (↑) shows increasing trend; (↓) shows decreasing trend;*** 0.001 level of significance; ** 0.01 level of significance;* 0.05 level of significance.

Table 4: Sen's slope for rainfall and temperature across various cities for different seasons

	Chennai	Bengaluru	Delhi	Hyderabad	Mumbai	Kolkata
			Rainfall (mm/year)			
Annual	3.456	1.008	-5.400	2.869	8.107	-1.263
Pre-monsoon	0.093	0.673	0.071	0.442	-0.019	0.760
Monsoon	1.623	0.563	-4.396	2.355	7.825	-3.043
Post-monsoon	2.231	0.029	-0.212	-0.134	0.434	-0.113
Winter	-0.036	-0.031	-0.095	0.175	-0.047	-0.170
			Temperature (°C/ year)			
Annual	0.014	0.013	0.003	0.009	0.005	0.011
Pre-monsoon	0.015	0.013	0.005	0.007	-0.003	0.012
Monsoon	0.011	0.014	0.003	0.008	0.0112	0.011
Post-monsoon	0.017	0.014	0.007	0.018	0.010	0.013
Winter	0.018	0.013	-0.006	0.007	-0.006	0.011

The analysis of Mann-Kendall statistics and Sen's Slope estimation across six major Indian cities reveals significant spatial and seasonal variations in climate pattern. The rainfall trend shows that Delhi is undergoing sharp and significant decline in annual and monsoon rainfall (Rana *et al.,* 2012). It indicates a growing vulnerability to water scarcity which reduces the agricultural productivity and increase heat stress. Cities like, Mumbai and Hyderabad are experiencing increasing trend in rainfall during the monsoon season. It causes the risk of urban flooding and demands drainage management systems (De *et al.,* 2013). Post-monsoon and winter rainfall are generally declining Delhi and Kolkata, which may affect groundwater recharge and winter crop production (Narjary *et al.,* 2014). In terms of temperature, consistent increase in warming trend is observed in Chennai followed by Bengaluru, Kolkata, Hyderabad and Mumbai across all seasons. However, Delhi shows an unusual pattern with no significant annual warming and slight cooling in winter (Sultana and Satyanarayana, 2018; Yadav *et al.,* 2014). Overall, these findings emphasize the urgent need for climate-resilient urban planning, sustainable water management, heat mitigation strategies and improved early warning systems.

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REFERENCES

De, U., Singh, G., and Rase, D. (2013). Urban flooding in recent decades in four mega cities of India. *J. Ind. Geophys. Union*, 17(2): 153-165.

Gupta, R. (2025). GIS-Based Analysis of Land Surface Characteristics and Urban Heat Islands in Metropolitan Cities of India. *IJEG*, 10(3): 440-455. https://doi.org/10.26833/ijeg.1638818

Kumar, P. (2021). Climate Change and Cities: Challenges Ahead. *Front. Sustain. Cities*, *3*. https://doi.org/10.3389/frsc.2021.645613

Mann, H. B. (1945). Nonparametric Tests Against Trend. *Econom.*, 13(3): 245-259. https://doi.org/10.2307/1907187

Matthews, T. K. R., Wilby, R. L., and Murphy, C. (2017). Communicating the deadly consequences of global warming for human heat stress. *Proc. Nat. Acad. Sci.,* 114(15): 3861-3866. https://doi.org/10.1073/pnas.1617526114

Nandi, S., Patel, P., and Swain, S. (2023). IMDLIB: An open-source library for retrieval, processing and spatiotemporal exploratory assessments of gridded meteorological observation datasets over India. *India Environ. Model. Softw.,* 171*:* 105869-105869. https://doi.org/10.1016/j.envsoft.2023.105869

Narjary, Bhaskar, Kumar, S., Kamra, S. K., Bundela, D. S., and Sharma, D. K. (2014). Impact of rainfall variability on groundwater resources and opportunities of artificial recharge structure to reduce its exploitation in fresh groundwater zones of Haryana. *Current Sci.,* 107(8): 1305-1312.

Nichol, J. (2005). Remote Sensing of Urban Heat Islands by Day and Night. *Photog. Engg. Remote Sens.,* 71(5): 613-621. https://doi.org/10.14358/pers.71.5.613

Rana, A., Uvo, C. B., Bengtsson, L., and Parth Sarthi, P. (2012). Trend analysis for rainfall in Delhi and Mumbai, India. *Climate Dynam.,* ١)٣٨): 45-56.

Santhoshkumar, B., Sathyamoorthy, N. K., Geethalakshmi, V., Dheebakaran, G., Boomiraj, K., Manikandan, N., and Kumar, M. S. (2024). Prediction of drought–risk zones in Tamil Nadu using historical and global climate model data. *Current Sci.*, 127(3):340-351.

Subash, N., and Sikka, A. K. (2013). Trend analysis of rainfall and temperature and its relationship over India. *Theor Appl Climatol.,* 117(3-4): 449-462. https://doi.org/10.1007/s00704-013-1015-9

Sultana, S., and Satyanarayana, A. N. V. (2018). Urban heat island intensity during winter over metropolitan cities of India using remote-sensing techniques: impact of urbanization. *IJRS*, *39*(20): 6692-6730. https://doi.org/10.1080/01431161.2018.1466072

Waghaye, A. M., Rajwade, Y. A., Randhe, R. D., and Kumari, N. (2018). Trend analysis and change point detection of rainfall of Andhra Pradesh and Telangana, India. *J. Agrometeorol.,* 20(2): 160-163. https://doi.org/10.54386/jam.v20i2.532

Yadav, R., Tripathi, S., Pranuthi, G., and Dubey, S. (2014). Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand. *J. Agrometeorol.,* 16(2): 164-171. https://doi.org/10.54386/jam.v16i2.1507